DEVELOPMENT OF NASA'S NEXT GENERATION L-BAND DIGITAL BEAMFORMING SYNTHETIC APERTURE RADAR (DBSAR-2)

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ABSTRACT

NASA's Next generation Digital Beamforming SAR (DBSAR-2) is a state-of-the-art airborne L-band radar developed at the NASA Goddard Space Flight Center (GSFC). The instrument builds upon the advanced architectures in NASA's DBSAR-1 and EcoSAR instruments. The new instrument employs a 16-channel radar architecture characterized by multi-mode operation, software defined waveform generation, digital beamforming, and configurable radar parameters. The instrument has been design to support several disciplines in Earth and Planetary sciences. The instrument was recently completed, and tested and calibrated in a anechoic chamber.

Index Terms*— *Digital Beamforming, interferometry SAR, InSAR.

1. INTRODUCTION

DBSAR-2 is a state-of-the-art airborne L-band radar instrument recently developed at the NASA Goddard Space Flight Center (GSFC). The instrument builds upon the technology path set out by the Digital Beamforming Synthetic Aperture Radar (DBSAR) [1], and the Ecosystems SAR (EcoSAR) [2][3], leveraging recent NASA Earth Science Technology Office (ESTO) investments that seek to enable fully polarimetric digital beamforming multimode radar, high resolution measurements, and advanced digital radar waveform synthesis and processing.

DBSAR-2 has the potential of providing high quality data in support of several disciplines in Earth and planetary sciences while setting a path for future spaceborne and airborne NASA missions. Once operational, DBSAR2 will be one of the most advanced Digital Beamforming L-Band radar architectures for airborne applications developed at NASA.

The DBSAR-2 measurements will be applicable to a number of science study areas ranging from ecosystem structure, surface and sub-surface topography, soil freeze-thaw, ice sheet composition, glacier depth, and surface water, among many others. In particular for Earth science, these measurements will provide critical data on the interaction between permafrost and biomass with the atmosphere, helping us improve our understanding of the carbon cycle.

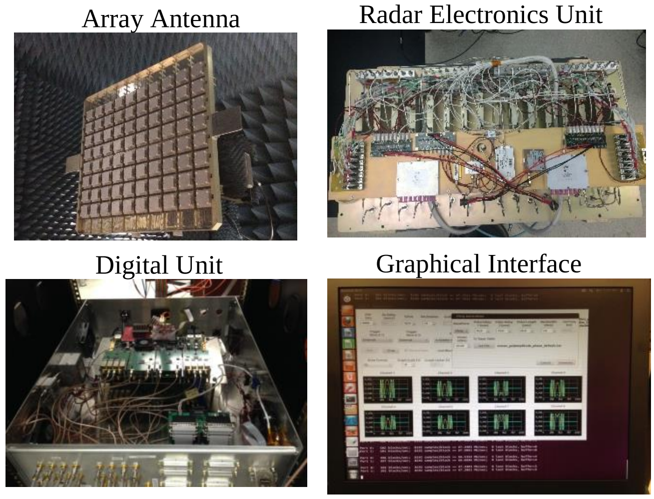


Figure 1 DBSAR-2 employs state-of-the-art technology to enable fully polarimetric digital beamforming multimode radar, high resolution (wideband) measurements, and advanced digital radar waveform synthesis and processing.

For instance, the polarimetric, and InSAR retrieval capabilities of the instrument will provide an efficient way to detect and document the surface expression of thawing permafrost, helping us quantify the spatial extent of thawing and the accelerating rate of $CO2$ and $CH4$ gas fluxes to the atmosphere. The instrument will also provide unique information on vegetation volumes and densities that can be used to map aboveground biomass, forest cover, disturbance from deforestation and degradation, forest recovery, and wetland inundation, helping us quantify carbon release into the atmosphere.

Furthermore, the large bandwidth and beamforming in DBSAR-2 will also expand the scientific measuring capability of the instrument by permitting the co-incident reception and processing of reflected signals from the Global Navigation Satellite System (GNSS-R) [6]. This capability enables the retrieval of complementary geophysical data, including ocean surface roughness

(winds), sea height, soil moisture, and ice classification, all relevant to climate change.

The antenna bandwidth also covers the passive portion of the L-band spectrum (1400 to 1426 MHz), making possible (passive) measurements of emissivity. This feature enables collocated active and passive measurements of geophysical parameters using a single antenna. Important performance parameters and characteristics achieved with this architecture are listed on Table 1.

2. ARCHITECTURE

DBSAR-2 employs a 16-channel radar architecture comprising three main subsystems: the Radar Digital Unit (RDU), the Radar Electronics Unit (REU), and the antenna, as illustrated in Fig. 2. The architecture is characterized by a multi-channel operation with software defined waveform generation for each radar transmit channel, and dedicated digital receivers for each radar receive channel.

The RDU is a custom FPGA-based processor capable of multi-channel arbitrary waveform generation, data acquisition, and onboard processing. The RDU is also responsible for radar timing, and data transfers.

Table 1 DBSAR-2 MAIN PARAMETERS

Frequency	1.26 GHz (L-band)
Bandwidth	50 MHz *
PRF	1 KHz to 10 kHz
Pulse Width	1μs to 100 μs
Polarization	HH, VV, VH, HV
Slant Range Resolution	3 m
Max. Radiated Power per polarization	16 W
Beam Steering Range	± 45 degrees
Antenna Type	Stack-Patch Array
Antenna Size	1 m x 1 m
Number of elements	80
Number of Active Sub-arrays	8
Sub-array Gain	10 dBi
Sub-array 3-dB Beamwidth	90 degrees
Array Gain (nadir)	19 dBi
Array 3 dB Beamwidth (1-way)	15.6 degrees
Array Side Lobes (1-way)	-24 db

*Upgradable to 200 MHz

The REU is made up 16 transmit/receive (T/R) modules that conditioned the transmit and receive signals, and provide several calibrations schemes.

The antenna consists of 80 stacked-patch elements arranged as sub-arrays (see Fig. 1). The antenna sub-arrays are aligned in the flight direction permitting relative amplitude and phase measurements between pairs or among groups of radar channels.

DBSAR-2's architecture builds upon its predecessor's, DBSAR [3], to perform beam steering on transmit (with no moving parts) and digital beamforming on receive. DBSAR-2's phase and amplitude weighting for beam steering and side lobe control are performed at base-band using the multiple arbitrary waveform generators.

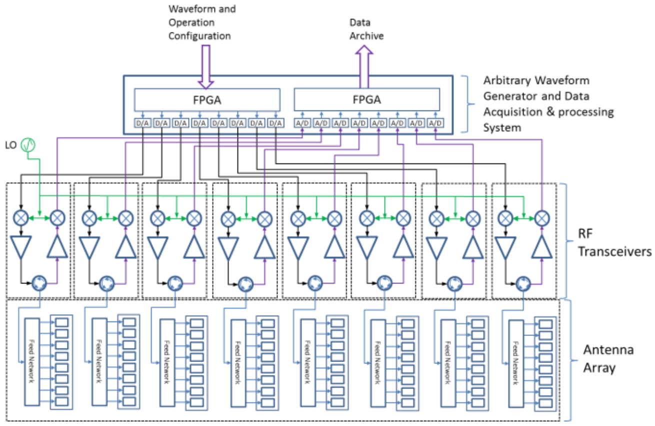


Figure 2 DBSAR-2's employs a 16-channel radar architecture (only 8 shown) comprising three main subsystems: the Radar Digital Unit (RDU), the Radar Electronics Unit (REU), and the antenna. This architecture allows considerable measurement flexibility.

Each waveform generator synthesizes a based band signal in the 95 MHz to 145 MHz frequency range with the appropriate phase and amplitude weights. Beamforming on receive can be performed on-board, or processed off-line by coherently capturing the raw complex data. This architecture allows considerable measurement flexibility including the generation of customized transmit and receive beams, imaging both sides of the flight track (simultaneously or time interleaved), post processing synthesis of multiple beams, variable incidence angle, swath width and ground resolution.

3. SYSTEM DESCRIPTION

The **Radar Digital Unit (RDU)** features an FPGA-based programmable digital waveform synthesizers system with 16 time-synchronous and phase-locked digital waveform generators (with independent amplitude and phase control), and a reconfigurable data acquisition and real-time processor with 16 independent receive channels. Figure 6 shows a simplified block diagram for the Digital Electronics Unit.

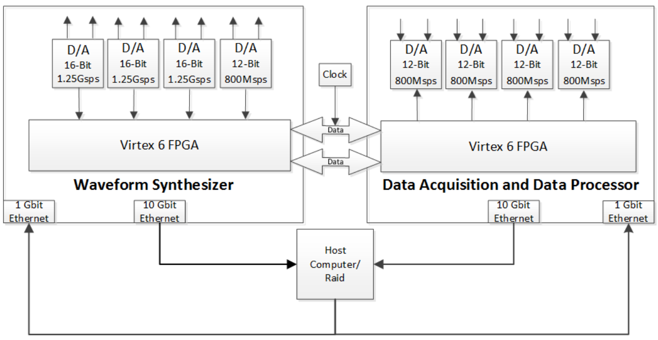


Figure 3 DBSAR's Radar Digital Unit Waveform Synthesizer, Data Acquisition and Processor Unit architecture.

The waveform synthesizers, data acquisition and processors are controlled by custom Graphical Unit Interface (GUI) (see fig. 1) running on Linux based servers

which performs real-time configuration, monitoring, and data archiving. The RDU supports 1 G-bit and 10-Gbit Ethernet for configuration, housekeeping, and data transfer to the host computers.

The **Radar Electronics Unit (REU)** consists of 16 transceiver modules (see figs. 1 & 4) capable of supporting a full polarization operation. Each T/R module includes a 2-Watt solid state power amplifier (SSPA), low noise amplifier (LNA), circulator, coupler, filters, and control switches. The modules also include closed loops for robust calibration, dynamic beam control and adaptive waveform generation. The transceivers were designed on printed circuit boards and used surface mount miniature components, reducing size (dimensions 2.54 cm x 10 cm x 27.6 cm.) while exhibiting high RF performance.

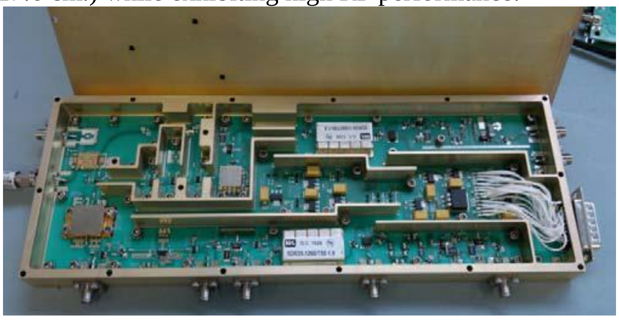


Figure 4 One of DBSAR-2's transceiver module. A pair of modules make up one DBSAR polarimetric channel.

The **antenna** (see figure 1) is based on a custom stacked patch aperture-couple design that permits polarimetric radar operation with bandwidths up to 500 MHz and cross-polarization isolation of 35 dB. 80 elements make up the antenna with only the 64 inner elements active. The antenna was tested in the anechoic chamber at NASA GSFC. Sub-array VSWR measurements and far field antenna patterns indicated successful operation of the antenna. Far field measurements were performed with the antenna main beam steered at several angles using delay lines. Figure 5 shows antenna patterns generated at the 1.26 GHz center frequency.

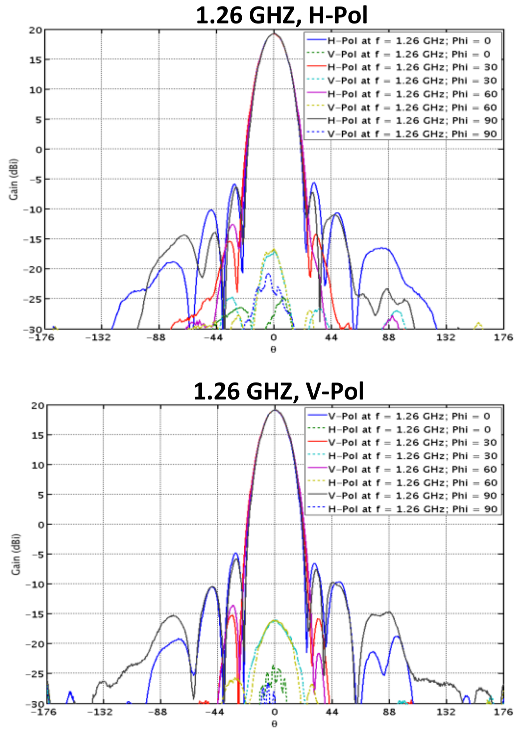
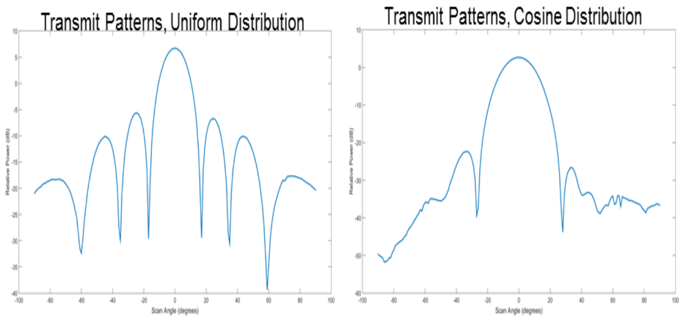


Figure 5 DBSAR-2 co-pol and cross-pol far field antenna patterns generated at 1.26 GHz. Top plot: Horizontal polarization. Bottom plot: Vertical polarization.

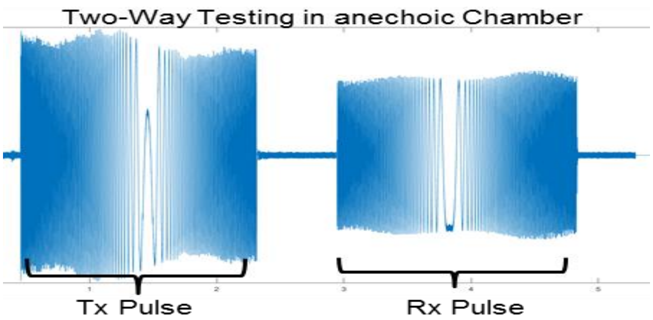


Although, DBSAR-2 will be compact to allow installation on a range of aircrafts, our first step was to integrated it and fly it on NASA's P3 and C-130 aircrafts. The antenna radome design, originally design for the P3, can also be flown on the C-130 through the use of a custom aerodynamic fairing.

4. SYSTEM CALIBRATION

DBSAR-2 was fully characterized at NASA Goddard's Electromagnetic Anechoic Chamber (GEMAC). The chamber measurements were used to generate steering coefficient vectors various look angles and amplitude taper.

Lastly, we successfully tested two way measurements in both polarizations and cross pols using an optical delay line system in the anechoic chamber. This measurements allowed us to test the full operational functionality of the system (Tx and Rx beam steering, radar timing, two way gain and dynamic range, and radar impulse response).



3. CONCLUDING REMARKS

The DBSAR-2 development seeks to demonstrate the Next Generation Digital beamforming SAR. The instrument's subsystems have been completed, integrated and calibrated in the laboratory and in the anechoic chamber. First test flights are scheduled in summer of 2016. This technology will help established the Next Generation DBSAR capability as a science instrument while setting a path future Earth science and planetary exploration SAR missions.

5. REFERENCES

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